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**METHOD AND APPARATUS FOR MONITORING
THE QUALITY OF OPTICAL LINKS**

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METHOD AND APPARATUS FOR MONITORING THE QUALITY OF OPTICAL LINKS

Technical Field

5 The devices, methods and systems described herein relate generally to optical correlation and more particularly to temporal optical correlation.

Cross-Reference to Related Application

This application claims priority to U.S. Provisional Application entitled "Method and Apparatus for Monitoring the Quality of Optical Links," serial number 60/430,214, filed December 2, 2002, which is incorporated herein by reference in its entirety. The present application is further related to contemporaneously filed U.S. Non-Provisional Applications entitled "Optical Correlation Device and Method" and "Method and Apparatus for Combining Optical Beams," based on U.S. Provisional Application Serial Numbers 60/430,207 and 60/430,213, respectively, each of which is incorporated herein by reference in its entirety.

Background

In a fixed network, the availability and the quality of transmission paths change dynamically. These changes are even more frequent in networks consisting of mobile stations in a hostile environment. An effective network should know at all times what paths exist and which are the best among them, and switch rapidly to new paths as the situation changes.

When a bit stream is sent over any optical link, it may undergo degradation due to attenuation, dispersion, noise, and jitter, among other things. As the shape and amplitude of the bits change, the receiver's ability to reliably distinguish 1's from 0's is also reduced. In current technology, the degree of degradation is typically measured by sending a very long pseudo-random bit stream over a link and comparing the receiver's best guess for each bit with the original signal. At a typical phone line bit error rate (BER) of 10^{-9} , a billion bits must be received on the average before a single error is detected, and usually at least 100 errors are required (10^{11} bits) for the measurement to be statistically significant. For data links, BER's of 10^{-12} are not uncommon. To receive,

then, the requisite 10^{14} bits, about 40 minutes are required at the fastest bit rate (40Gb/s) and even longer for more typical links. Alternatively, one may measure the eye diagram, in which one collects many bits (thousands), converts them to an electronic signal, and superposes the various bits on an oscilloscope. Then sophisticated electronics examine a 5 window inside the eye and look for transgressions of the signal into the opening of the eye. The advantage of the eye diagram technique is that attenuation, dispersion, jitter, and noise can all be determined from the shape of the eye, but it may require 20 to 30 seconds at the fastest bit rate, and the information has to be processed by a person, and then acted on.

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Summary of the Invention

The following presents a simplified summary of apparatus, systems and methods associated with monitoring the quality of optical links to facilitate providing a basic understanding of these items. This summary is not an extensive overview and is not 15 intended to identify key or critical elements of the methods, systems, apparatus or to delineate the scope of these items. This summary provides a conceptual introduction in a simplified form as a prelude to the more detailed description that is presented later.

The present invention employs optical correletion to monitor and determine the Quality of Service (QoS) of an optical link. According to the present invention, a known 20 signal is sent across the link. The received signal, which has acquired attenuation, dispersion, noise and jitter, is compared to the original signal using optical correlation, a technique that can be much faster than any electronic computation. The quality of information can be obtained in the time of four bits, which at a bit rate of 40Gb/s is 100 picoseconds.

25 According to a first aspect of the present invention, a method for determining a quality of an optical link is disclosed. The method includes identifying a known signal and transmitting and receiving the signal over an optical link. The method also includes comparing the received signal to the known signal using optical correlation. The method further includes determining a quality of the optical link based on the comparison.

30 Certain illustrative example apparatus, systems and methods are described herein in connection with the following description and the annexed drawings. These examples

are indicative, however, of but a few of the various ways in which the principles of the apparatus, systems and methods may be employed and thus are intended to be inclusive of equivalents. Other advantages and novel features may become apparent from the following detailed description when considered in conjunction with the drawings.

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Brief Description of the Drawings

Comprehension of the invention is facilitated by reading the following detailed description, in conjunction with the associated drawings, in which: .

10 Figure 1 is a schematic block diagram of a prior art correlator;
Figure 2 is a signal diagram depicting an example sent signal and a corresponding example received signal;

Figure 3A-3D are signal diagrams illustrating attenuation, dispersion, noise and jitter; and

15 Figure 4 is a flowchart illustrating an example methodology for determining the quality of an optical link.

Detailed Description

20 Referring first to Figure 4, there is illustrated an example methodology 400 for determining the quality of an optical link. At block 405, a known signal is identified for use in the methodology. At block 410, the known signal is transmitted and received over the optical link to be monitored. According to block 415, the received signal is compared to the known signal using optical correlation techniques, described in greater detail below. The quality of the optical link is then determined at block 420 based on the results of the comparison performed at block 415.

25 According to one embodiment, the correlation of the received signal $r(t)$ with the known signal $s(t)$, also referred to as the sent signal, is performed where t represents time. The cross-correlation function:

$$c(t) = \int_{-\infty}^{\infty} s(\tau)r(t - \tau)d\tau \quad (1)$$

30 is a measure of how similar $r(t)$ and $s(t)$ are. A correlation can be implemented in a discrete system by sampling the received signal N times: as:

$$c(t) = \sum_{k=0}^{N-1} s_k r(t - k\tau_k) \quad (2)$$

Here, the sent signal is represented as discrete weights s_k . In cases of amplitude, or incoherent correlation, the weights will be 1's and 0's. The received signal is replicated N times. The first duplicate is shifted in time by one increment, the second is shifted by 5 two increments, and so on. Each time-shifted replica of $r_k(t)$ is multiplied by a weight $s_k(t)$, and the resulting products are summed. The larger N is, the higher resolution the correlation and the more accurate the measurement.

Referring now to Figure 1, there is illustrated an example correlator 100 which may be used by the present invention. Of course, an alternate correlator such as the 10 optical correlator described in U.S. Provisional Application serial number 60/430,207, for example, may also be used by the present invention. The received signal 105 is sent to a tapped delay line 110. At each tap, a small amount of the power is siphoned off. There is a time delay τ between each tap. Each of the signal replicas, which should all be of substantially the same amplitude, is then given a weight s_k . The weights 120 can be real, 15 implemented with amplitude weights, or complex, using phase shifters, possibly in combination with amplitude weights. For digital signal monitoring for quality of service, the s_k 's will be either 1's or 0's.

The resulting correlation function 135, has a length in time of twice the input time period. This time is actually set by, and may vary according to, the design of the tapped 20 delay line 110.

In one possible configuration, one can send a test signal consisting of a "1" bit with "zero" on either side, as illustrated by signal diagram 210 of Figure 2. The total signal time is $2T$, since here only one half of each zero is sent. Longer "zero" periods of a full bit may be used for extremely degraded signals. A received signal of interval $2T$ is 25 sampled, where T is the bit period, and the resulting correlation function will occupy a time $4T$. If the two signals are identical, Equation (2) becomes an autocorrelation, and has a sharp peak in the center, and low side lobes. If the signals are less well matched, the peak decreases and the information on either side of the peak increases. Signal diagram 220 of Figure 2 shows the shape of the pulse at the "receive" end of the link. It

indicates that the received signal is degraded, namely attenuation and dispersion are shown.

Referring now to Figures 3A-3D, there is illustrated the resulting correlation functions for received signals showing only attenuation (3A) and only dispersion (3B).

5 Note that fifty percent dispersion is defined as the point at which half the energy lies outside the original pulse. It can be seen that attenuation reduces the height of the correlation peak, while dispersion both reduces the peak and changes its shape. This much information can be obtained in a single correlation time $4T$.

10 Noise and jitter must be measured statistically over multiple correlations. Figure 3C shows the variation in the peak amplitude as a function of noise with a Gaussian distribution of standard deviation σ . As illustrated in Figure 3D, jitter is manifested as a variation in the location of the peak, shown here for an 8-bit duration.

15 The resolution with which the correlation can be done depends on the number of taps in the tapped delay line of the correlator. If the data rate is already as fast as electronics can switch, then an electronic tapped delay line is useless as it could produce at most one sample per bit period. Therefore, the present invention employs an optical correlator to perform the correlation. An optical tapped delay line can produce delay times that are arbitrarily small, depending as they do only on the difference in path lengths inside the delay line, rather than on any switching function. Thus, one can 20 produce hundreds of thousands of taps during the time an electronic transmission of a single bit. That is, even the fastest possible bit stream can be sampled with hundreds of samples per bit resolution using optical techniques.

25 The correlation results in an optical time-varying signal, which may then be converted to an electronic signal for thresholding, or thresholded optically. If the bit rate is 40Gb/s, the total length of the correlation signal in our example is 100ps. A simple thresholding operation can determine whether the peak exceeds some minimum standard, and thus provide an ultra-high speed general evaluation of the link quality.

30 At the same time, the correlation signal can be replicated and subjected to other processing in parallel. For example, to determine the level of dispersion, and to isolate its effects from those of attenuation, one may wish to evaluate the curvature of the correlation peak. An optical correlator or optical matched filter can perform this function

as well. By correlating the received, and presumably dispersed pulse, with the triangle function expected from an un-dispersed pulse, the peak of *that* correlation will directly reflect the amount of deviation from the ideal. Thus, this information can be obtained in the next $8T$ (200 ps for a 40Gb/s signal).

5 Alternatively, standard transversal filtering techniques can be used to evaluate the shape of the first correlation function, for example to take its derivatives. The correlation device can be used as a transversal filter by varying the weights appropriately. One might decide to perform multiple filtering tasks to separate attenuation and dispersion effects, for example.

10 To obtain noise and jitter information, one would evaluate the variation in peak height and location over a number of samples. It takes many bit periods, perhaps hundreds or thousands, to collect a statistically significant sampling. By employing an optical correlator, this task can be accomplished much faster, perhaps in nanoseconds to microseconds, compared to traditional techniques that require minutes.

15 Finally, it should be noted that when a zero and a one are transmitted, as in Figure 2, the corresponding weights for the correlation are also 1's and 0's. In incoherent correlators, this amounts to an amplitude weight of either "pass the beam" or "block the beam." In the optical correlator, the light beams that will be blocked do not need to be generated at all, and thus the resolution of the correlator is actually twice the number of

20 taps in the delay line.

25 Although the invention has been described in terms of specific embodiments and applications, persons skilled in the art can, in light of this teaching, generate additional embodiments without exceeding the scope or departing from the spirit of the claimed invention. Accordingly, it is to be understood that the drawing and description in this disclosure are proffered to facilitate comprehension of the invention, and should not be construed to limit the scope thereof.